Helical precooler channels

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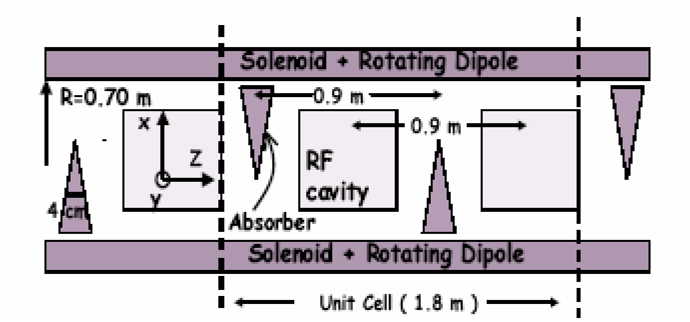
- linear 6D cooling channel is useful
  - reduce injection requirements for rings
  - reduce losses from particles falling out of rf bucket

- helical cooling channels have been suggested
  - Y. Derbenev developed the linear theory (MC185)
  - cooling channel designed by V. Balbekov (MC146)
    - results ≈confirmed in Geant4 simulation (MC193)
  - currently under study by Muons, Inc.

- reexamine helical cooling channels
  - review previous Balbekov channel results
  - ICOOL simulations of Balbekov channel
  - ICOOL simulations of gas-filled Balbekov channel

Balbekov helical cooling channel

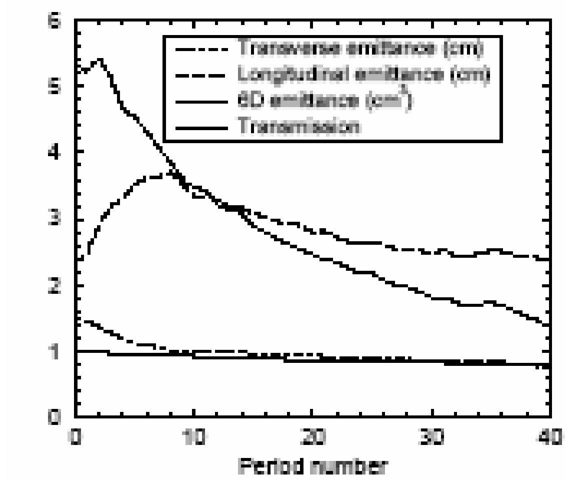
72 m long, 40 x 1.8 m cells
$B_S = 5$ T, $b_0 = 0.3$ T
201 MHz, 14 MV/m, 30^o phase
14.7^o LiH wedge absorbers
dipole field tapered on/off over 8 cells
simulations described in MC146 and MC193



Input beam parameters

$\sigma_X = \sigma_Y = 3.25$ cm
$\sigma_Z = 10$ cm
$\sigma_{PX} = \sigma_{PY} = 48.7$ MeV/c
$\sigma_{PZ} = 18$ MeV/c
L_Z for 5 T solenoid
momentum – transverse amplitude

Balbekov channel performance



Simulation results for correlated Gaussian input beam

simulation	ε_{TN} [mm]	ε_{LN} [mm]	Tr
MC146 (VB)	15 → 7.5	24 → 24	0.81
MC193 (DE et al)	15 → 5.9	46 → 20	0.85

- VB found ~x2 reduction in ε_{TN} and no reduction in ε_{LN}
- DE et al found ~x2.5 reduction in ε_{TN} and ~x2 reduction in ε_{LN}
- most of DE et al reduction in ε_{LN} comes from the large initial
  - value
  - correlation handled right?
- DE et al used unrealistic RF cavity model
  - 1 cm sinusoidal gaps with G = 1.2 GV/m !!!
  - minimizes or ignores
    - transit time effects
    - radial dependence of acceleration
      - additional momentum-position correlations
    - phase difficulties from helical reference path

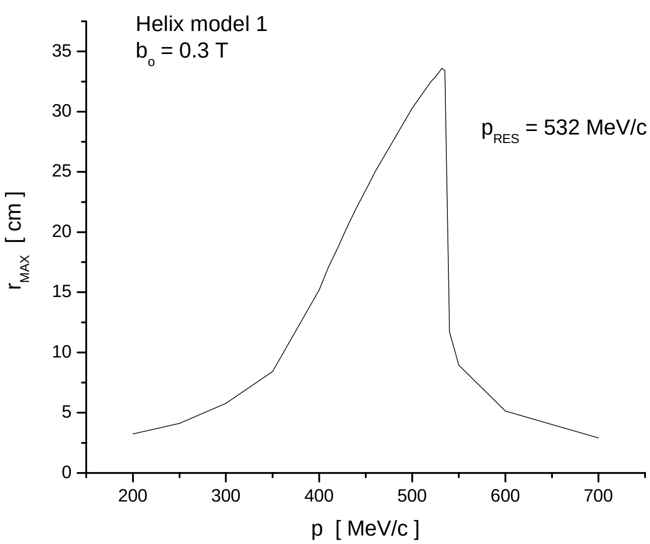
ICOOL simulation of VB cooling channel

(1) empty lattice (no RF or absorbers)

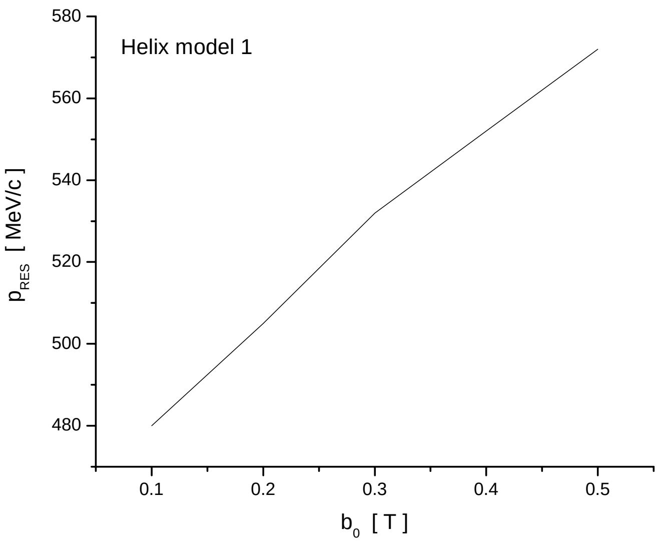
• field models
  1) simple rotating dipole (same as previous simulations)
  2) helical current sheet
    modified Bessel function solution satisfies ME

• helix channel with solenoid has resonance instability
  when $\lambda_L = \lambda_H$

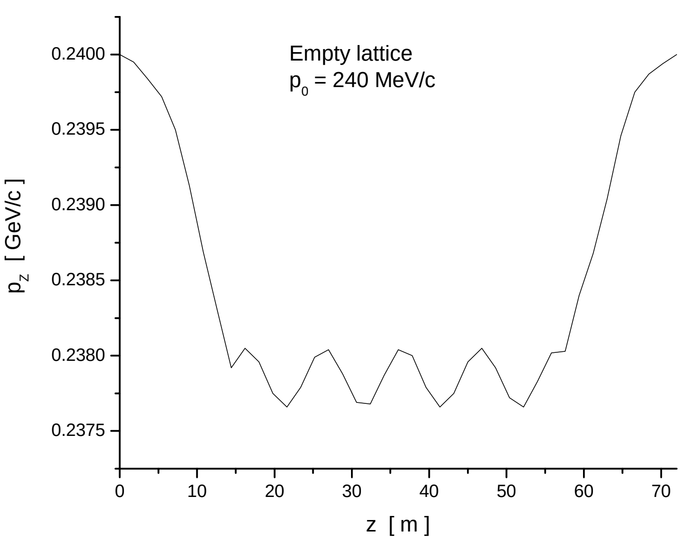
$$p_{res} = \frac{eB_S \lambda_H}{2\pi} = 430 MeV / c$$



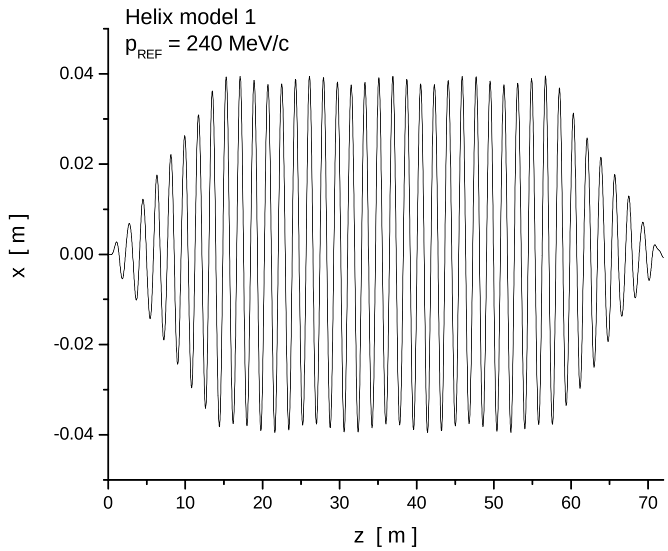
• p_{res} higher than predicted by linear theory



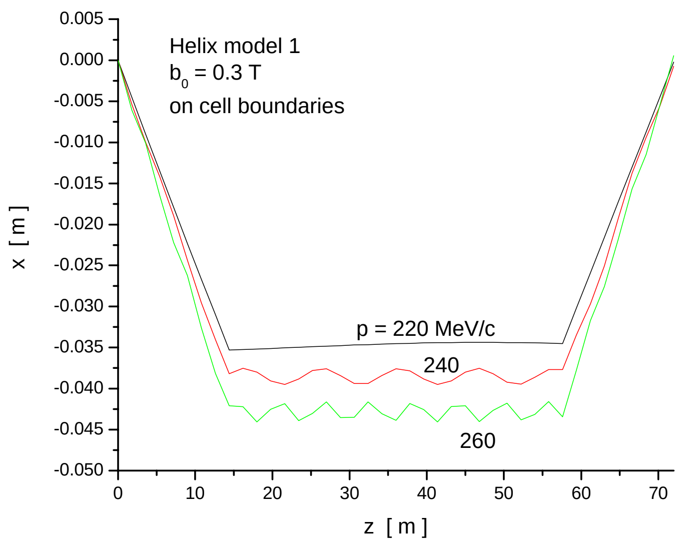
- p_{res} depends on b_0
  higher b_0 gives more dispersion
- choose p_{ref}
  closer to p_{res} (i.e higher) gives more dispersion
  but …
    get more modulation and emittance increase
    rapidly decreasing bucket area
  take p_{ref} = 240 MeV/c (same as VB)



- p_Z falls as p_T increases (taper)
- v_Z changes for “reference” particle => difficulties ahead



• see effect of tapered turn-on and -off of dipole field
• position modulation ~ 3% cell to cell



• clear dispersion at cell boundaries
• D ~ 0.4 cm / (20/240) ~ 5 cm
• dispersion along x at cell boundaries

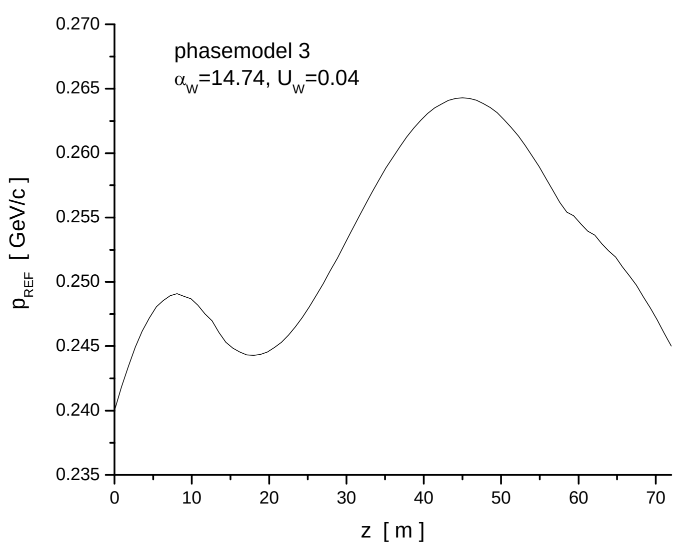
(2) real channel: single particle tracking, no stochastics

• include RF and absorbers according to VB design
  201 MHz RF with 14 MV/m
  use ICOOL pillbox cavities (different)
    4 x 25 cm cavities / cell
  alternate absorber direction along ±x

• how do you set the cavity phases?

1) use VB wedge design (α_W=14.7°, U_W=4 cm)
  tried to individually tune RF cavities to get ref particle to follow
    empty channel momentum profile
  => not successful
  probably due to transit time effects in realistic cavities ≠ simple gaps

2) set cavity phases using ICOOL ref particle (phasemodel 3)
  straight, constant velocity RF reference particle
  real physics reference particle is helical and oscillates in velocity
  expect additional velocity fluctuations from phase mismatch



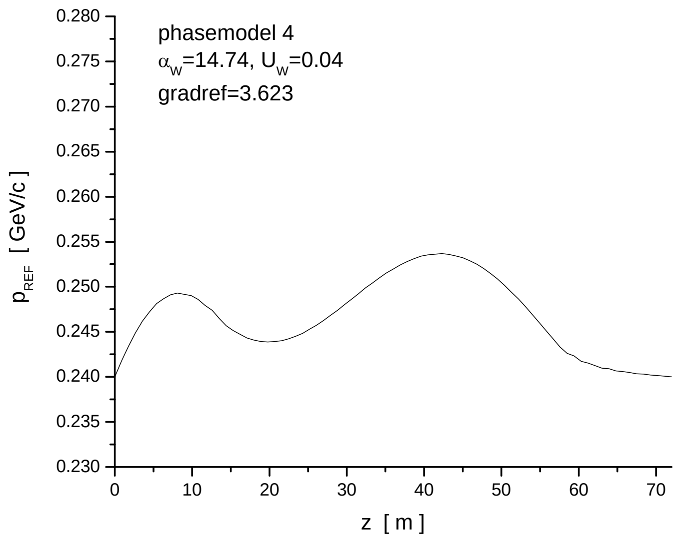
• get ~13% fluctuation

3) set cavity phases using ICOOL ref particle (phasemodel 4)

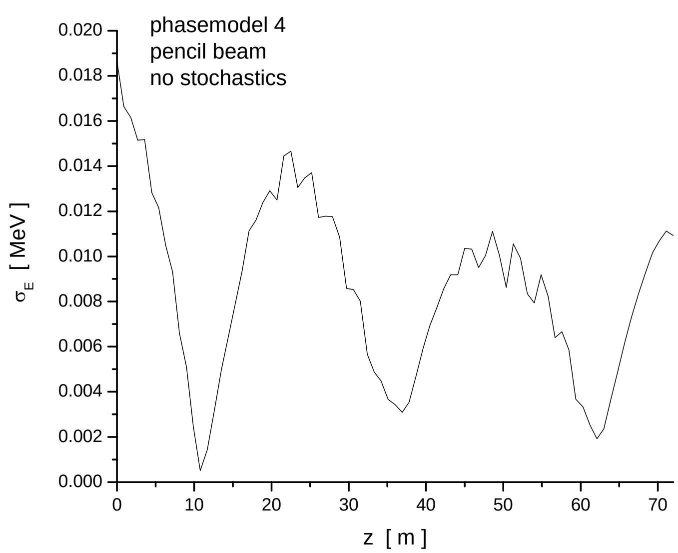
straight RF reference particle, but p goes up and down

try to keep α_W and U_W at VB values

adjust GRADREF to get p_{REF} at the end of channel



• get ~6% fluctuation



• see decrease of energy spread in ideal channel

• does not continuously decrease energy spread

when $\sigma_E \rightarrow 0 \Rightarrow \sigma_t$ gets large

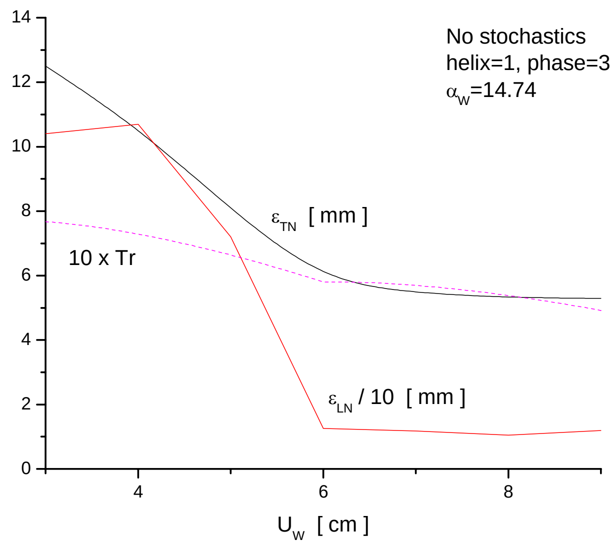
enters RF with $\Delta\varphi \Rightarrow \sigma_E$ grows again

(3) real channel: Gaussian beam tracking

• use VB input beam
• apply VB initial correlation

$$E = E_o \sqrt{1 + \left(\frac{p_T}{mc} \right)^2} + \sigma_E$$

• significant differences in models => vary some parameter
• study cooling performance as a function of U_W
• use ECALC9F with 100< p< 320 MeV/c cut



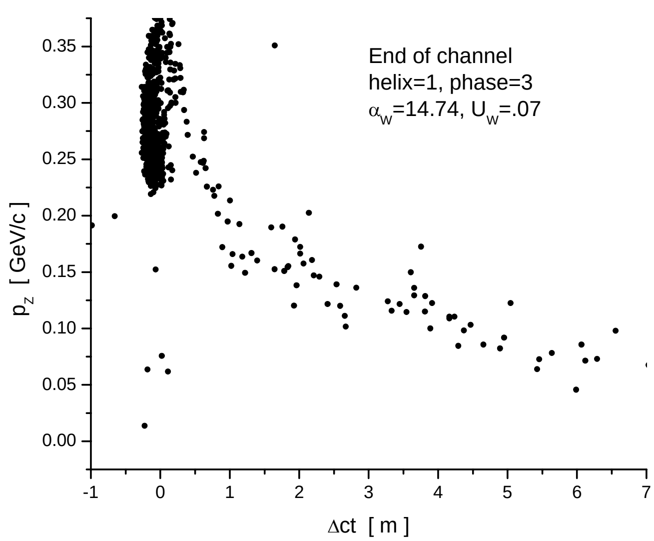
ICOOL cooling performance with Gaussian beam

include stochastics
$\alpha_W = 14.74^o$, optimized U_W
100< p< 320 MeV/c cut in ECALC9
initial emittances

ε_{TN} = 11.0 mm
ε_{LN} = 28 mm

helix model	phase model	U_W [cm]	ε_{TN} [mm]	ε_{LN} [mm]	Tr [%]
1	3	7	8.0	17	48
	4	6	7.8	20	54
2 (D)	3	7	7.8	22	65

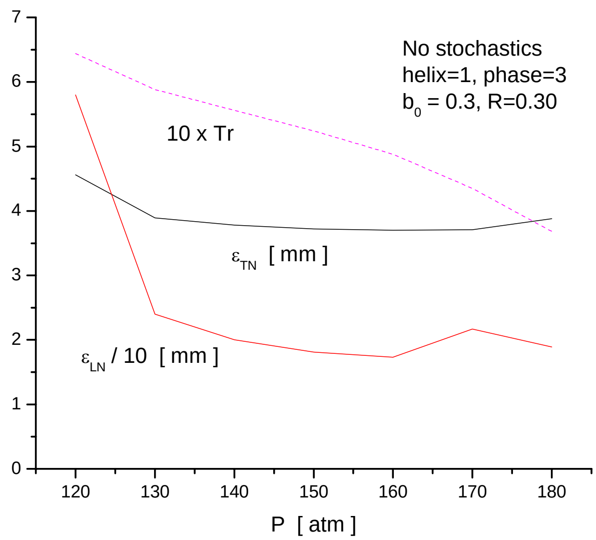
- channel performs very poorly !!!
- sheet field has better transmission



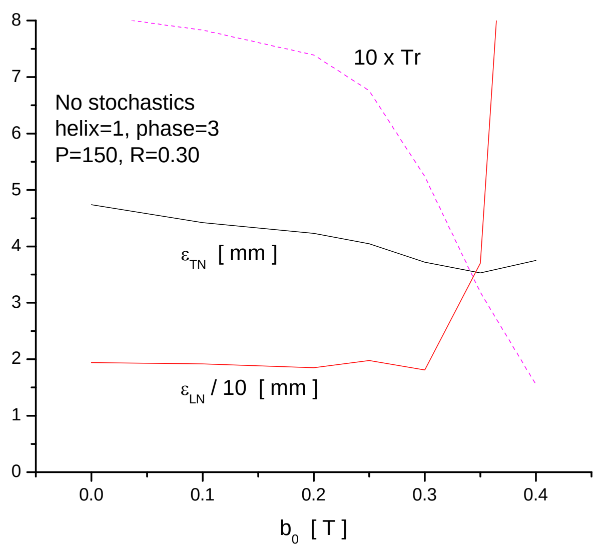
- clear problems keeping beam bunched

Gas-filled helical channel

• start with VB channel
• remove wedge absorbers
• fill with high pressure H_2 gas
• use ECALC9 with $100 < p < 320$ MeV/c cut



pressure curve



dipole strength curve

ICOOL cooling performance

include stochastics
initial emittances

ε_{TN} = 11.0 mm

ε_{LN} = 28 mm

helix	phase	P [atm]	ε_{TN} [mm]	ε_{LN} [mm]	Tr [%]
1	3	140	4.9	26	50
	4	160	5.1	27	50
2 (D)	3	160	5.2	25	56
2 (D+Q)	3	160	5.5	30	45

- slightly better performance than channel with LiH wedges
- no evidence for longitudinal cooling
- adding quad term to sheet model makes it worse